Microphysical and Radiative Evolution of a Cirrus Anvil on 21 July 2002

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Introduction:

Global climate is sensitive to the microphysical properties of synoptic and convectively produced tropical cirrus clouds. Tropical cirrus properties have been measured in the past, but with limited instrumentation and aircraft, mostly due to their remote locations.

The Cirrus Regional Study of Tropical Anvils and Cirrus Layers Florida Area Cirrus Experiment (CRYSTAL-FACE) was carried out in July 2002 over south Florida. During this field campaign three aircraft took in-situ measurements of tropical cirrus and cirrus anvils. On 21 July a short-lived thunderstorm developed over southwest Florida. The WB-57F and Citation aircraft sampled the thunderstorm anvil from near beginning of formation to its dissipation. Because the anvil was isolated from other cloud systems in the region, this event represents an opportunity to study a cirrus anvil with minimal interference from other clouds and with a greater variety of instruments than previously possible.

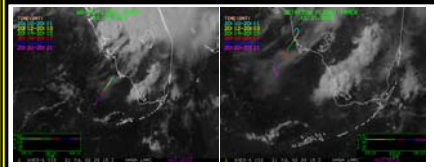

Fig. 1. Visible satellite images with track overlays of one of the legs completed by the WB-57F (left) and the Citation (right).

The WB-57F and Citation aircraft flew legs along the axis of the anvil. The prevailing winds in Fig. 1 are from the northeast.

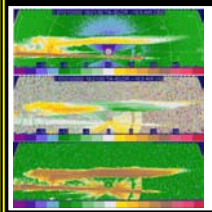

Fig. 2. ELDORA radar images of the 21 July anvil under study. The top image is reflectivity, the center image is radial velocity, and the bottom image is the normalized coherent power.

ELDORA radar images show the well-defined anvil and cirrus blow-off downwind from the storm. The anvil reaches an approximate height of about 8.0 km in Fig. 2. The ELDORA radar system was located on the P-3, which flew northwest-to-southeast legs south of the storm.

Aircraft Transects (Fig. 3) of Anvil Cirrus Blow-off

Citation:

- The size distribution is bi-modal, with modes located at about 25 µm and 100 µm maximum dimension. The second mode increases in maximum dimension with increasing distance from the upwind edge of the anvil.
- Total concentrations decrease with increasing distance from the upwind edge of the anvil due to evaporation; concentrations of particles larger than 100 µm increase with increasing distance.
- The extinction coefficient (β_{ext}) decreases with distance and time while the effective radius (r_e) remains constant with distance and time.
- Satellite (GOES-8 VISST) comparisons of r_e to in-situ measurements show good agreement. Satellite values are about 25 µm, while in-situ measurements are about 20 µm.

WB-57F:

- There is one mode in the size distribution at about 25 µm maximum dimension, which stays constant with time.
- The maximum dimension of the ice crystals does not exceed 360 µm.
- Values of β_{ext} ($\beta_{ext} \leq 2$ km^{-1}) measured by the WB-57F are an order of magnitude smaller than that measured by the Citation, indicating very tenuous cirrus.
- The in-situ r_e is significantly smaller than the satellite r_e. Note that the majority of the cloud is below the WB-57F flight level so that the cloud sampled may be transparent to the satellite.
- The mode size, β_{ext} , and r_e change very little between each leg.

Aircraft Transects

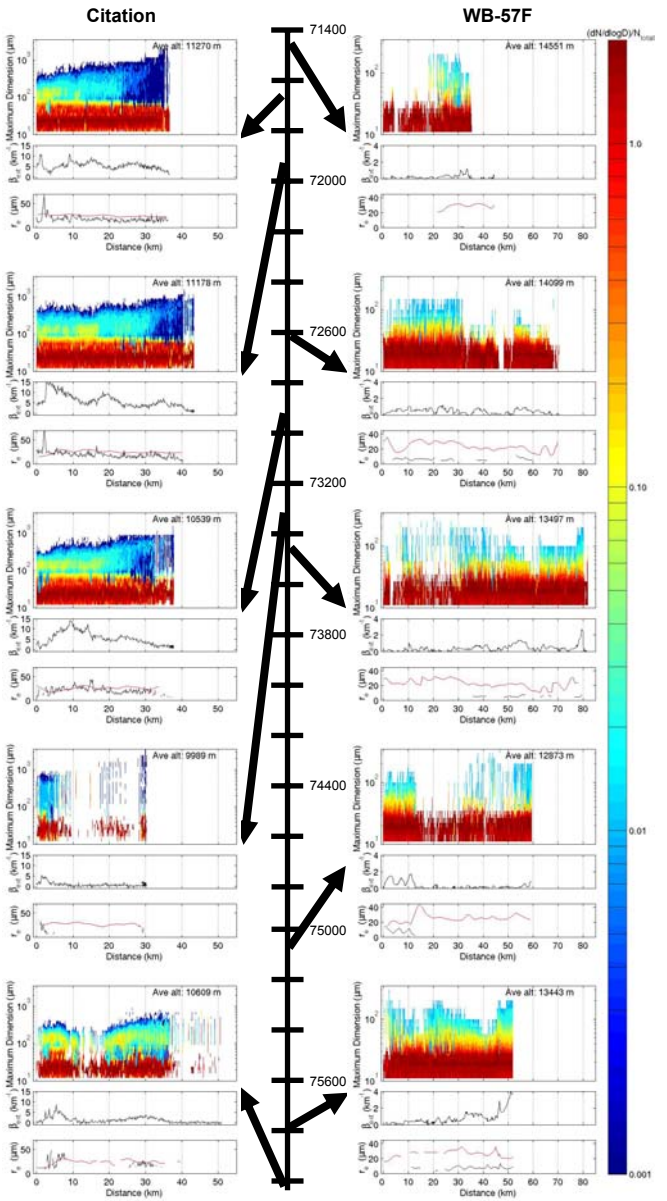

Fig. 3. Time-line with plots of normalized particle concentration, β_{ext} , and r_e for the Citation (left) and the WB-57F (right). The red line on the r_e plots is the satellite measured r_e. Distance is measured from the upwind to the downwind edges of the anvil. Time is seconds from UTC midnight.

Vertical Profile

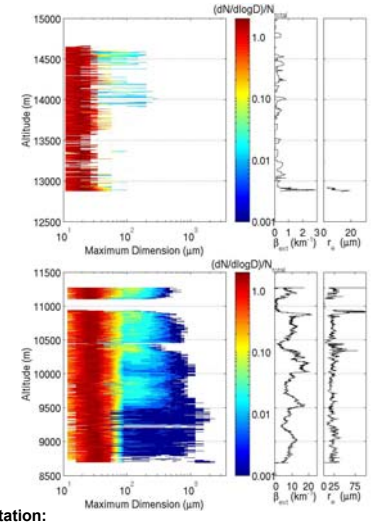

Fig. 4. Vertical profile plots for the WB-57F (top) and the Citation (bottom). Variables are the same as in Fig. 3.

Citation:

- There is a bi-modal size distribution, with modes at 25 µm and 100 µm maximum dimension.
- Particles > 400 µm likely have settled to the bottom of the cloud.
- There is a constant r_e profile with height.
- Vertically integrated β_{ext} during the profile time period gives τ_{vis}=21.7; simultaneous satellite retrievals of τ_{vis} range from 0.6 to 24.4, with a mean value of 7.8 ± 5.9.

WB-57F:

- The cirrus is very tenuous with small r_e and β_{ext}.
- There is a single particle mode at 25 µm maximum dimension.
- Vertically integrated β_{ext} during the profile time period gives τ_{vis}=0.3; simultaneous satellite retrievals of τ_{vis} range from 0.8 to 12.1, with a mean value of 3.9 ± 2.9.

Summary:

The cirrus anvil has a bi-modal distribution in the lower and middle levels. The smallest mode is around 25 µm maximum dimension while the largest mode varies depending on height and on distance along the axis of the anvil. At the upwind edge of the anvil, the largest mode is at about 100 µm maximum dimension. As distance increases towards the downwind edge of the anvil the mode shifts to about 600 µm maximum dimension. This shift is probably caused by the aggregation of cloud particles as they are advected downwind. The dependence of the largest mode on height is probably due to vapor deposition and aggregation, where particles larger than 400 µm probably settle to the bottom of the cloud. As the anvil evolves, the small mode remains at about 25 µm and continues to dominate the total number of particles. In the upper levels there is a mono-modal size distribution with a mode at about 25 µm. Like the lower and middle levels, the single upper level mode remains at a constant maximum dimension and accounts for the majority of total particles. However, the cloud in the upper levels is not as visibly thick as in the lower and middle levels.

The effective radius (r_e) for the cirrus anvil remains constant in the lower and middle levels during the anvil's lifecycle and does not depend greatly on distance from the anvil edge or on height. The r_e is smaller in the upper levels than in the lower and middle levels, but also remains constant during the lifecycle. Satellite retrievals of r_e suggest there is good agreement with in-situ measurements in the lower and middle levels. In-situ measurements of r_e in the upper levels are significantly smaller than satellite retrievals (probably because the cloud is transparent to the satellite at this level). Since the small mode dominates and r_e is constant during the anvil lifecycle, it appears that small ice crystals dominated the radiative properties of this cirrus anvil.

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